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ARAC Dispersion Modeling Support for January-March 1995 Vandenberg AFB Launches

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BACKGROUND

The Glory Trip (GT) 17–PA Peacekeeper launch originally scheduled at Vandenberg Air Force Base (VAFB) between 15 and 20 November 1994 was cancelled based on modeled toxic exhaust cloud calculations. The Missile Flight Control Branch, 30th Space Wing Safety Office (30 SW/SEY), made several successive "No Go" decisions using Version 7.05 Rocket Exhaust Effluent Dispersion Model (REEDM) with forecasted meteorological conditions. REEDM runs made from T-14 hours to T-30 minutes predicted that ground-level concentrations of hydrogen chloride (HCl) gas from the catastrophic abort case would exceed 5 ppm, the "instantaneous" ambient air concentration "Tier 2" limit at that time, modeled as a peak 1-minute cloud centerline concentration. Depending on the forecasted wind direction and speed at launch time, this limit was predicted to be exceeded sometimes at Base Housing, approximately 10 km southeast of the launch, and during other launch windows at the town of Casmalia, about 5 km east-southeast.

In late December 1994, the LLNL Atmospheric Release Advisory Capability (ARAC) program modeled the aborted November 1994 Peacekeeper launch and compared its results with REEDM. This initial comparison showed that the ARAC model predicted values about 1/3 as large as REEDM for the limiting case at Base Housing. Subsequently ARAC was asked to provide real-time modeling support to 30 SW/SEY during the rescheduled Peacekeeper GT 17-PA launch in January 1995 and two Minuteman launches in February and March. This report first briefly discusses the model differences and then summarizes the results of the three supported launches.

EXPOSURE GUIDELINES FOR LAUNCHES

Two cases--**the nominal or normal launch and the catastrophic abort case**--are modeled for each successive forecasted sounding between T-14 hours to T-30 minutes. Table 1 lists the **exposure guidelines** used to determine if the public health would be at risk for each of the two launch cases. Because exposure to HCl is concentration dependent, the guidelines are interpreted as instantaneous ceiling values. This was modeled as a 1-minute value before 30 December 1994 and changed to a 1-second peak after the HQ AFSPC/SG memo on that date from Col. Machado.

TABLE 1. Launch Exposure Guidelines for HCl at VAFB

GUIDELINE	BEFORE 30 DEC 1994	AFTER 30 DEC 1994
Tier 2 - Cat. Abort	5 ppm for 1 minute	10 ppm for 1 second
Tier 3 - Nominal	1 ppm for 1 minute	1 ppm for 1 second

MODEL INPUTS AND PLUME RISE

For both dispersion models, the primary inputs are **source term** and **meteorological data**. ACTA, Inc. provided the source rate (HCl in g/s as a fraction of the missile fuel) and heat exhaust based on TRW data. A rawinsonde sounding (values of wind speed, wind direction, temperature and pressure with height) which has been **forecasted for launch time** is the primary meteorological input into the models. The mixing height is determined from the sounding vertical temperature profile.

The **nominal rocket exhaust cloud** is divided into several cylindrical volume sources at levels above ground. During the plume rise calculation each cylinder is transported by the mean wind speed and direction in each layer as determined from a rawinsonde sounding. The **catastrophic abort case** involves burning rocket fuel spread over an area on the ground. The emissions are put into a single ground-based spherical cloud initially, the radius of which is set by missile type. For every launch we studied, the catastrosphic abort case always produced concentrations closer to its corresponding Tier 2 exposure limit, and therefore was the limiting case.

REEDM uses a modified Briggs **plume-rise** code to calculate the final plume rise from the buoyant rocket exhaust cloud segments up to 3 km. ARAC uses the standard Briggs plume-rise code, but we adjusted the heat content so that the final rise closely matched the value produced by REEDM for each case. As shown in Figure 1, ARAC used 9 source elements for the nominal cloud up to 1.5 km. (Segments above 1.5 km were found to not contribute to ground-level concentrations within 20 km of the launch and therefore were not included.) Emissions from the propellent burn case were input into a single ground-level cloud for the catastrophic abort case.

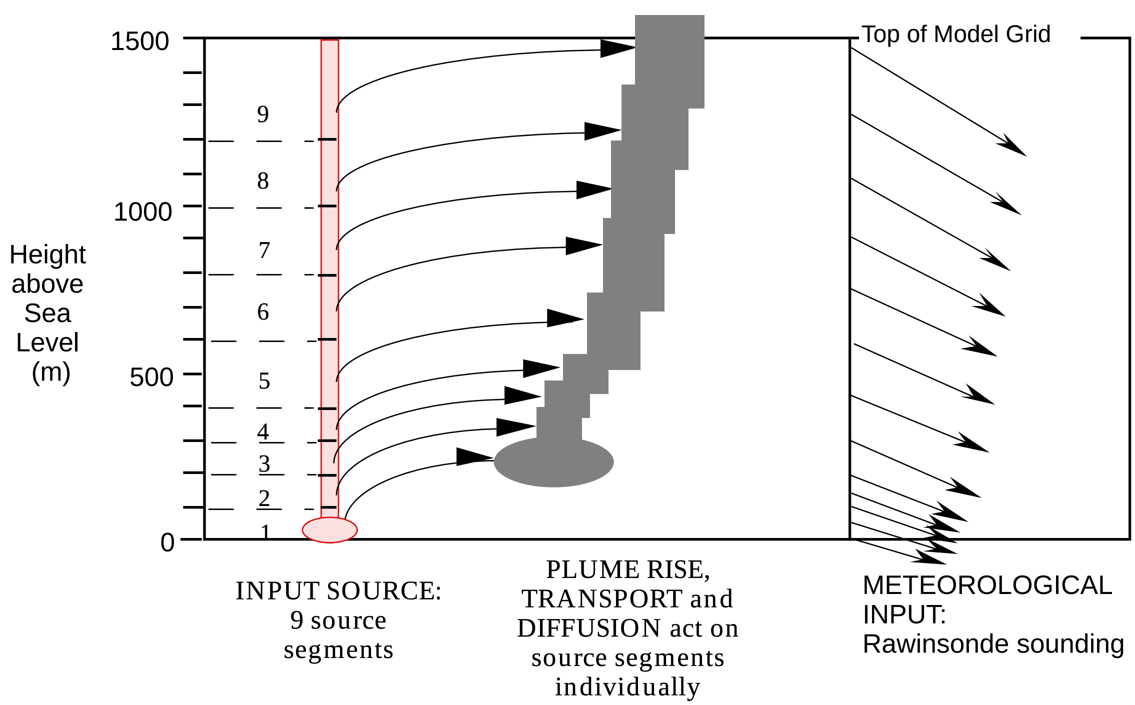

Figure 1. ARAC model simulation of plume rise from nominal launch

REEDM MODEL STRUCTURE

REEDM is a **steady-state Gaussian dispersion model** developed over the last decade under contract to NASA and USAF specifically to simulate dispersion of rocket exhaust. Figure 2 illustrates the basic structure of the model. REEDM uses a single wind speed and direction at the mean boundary layer height (half way up to the mixing height) to transport the exhaust cloud segments after they have achieved final plume rise. Dispersion in the crosswind and vertical directions is computed using a normal distribution adjusted for atmospheric stability and downwind distance. Maximum concentrations occur along the cloud centerline.

The nominal cloud rise model calculation has been compared with several photographic datasets. There have been no comparisons with data for the catastrophic abort cloud rise. While REEDM has Gaussian structure common to many regulatory models, its dispersion calculations have not been evaluated against tracer measurements.

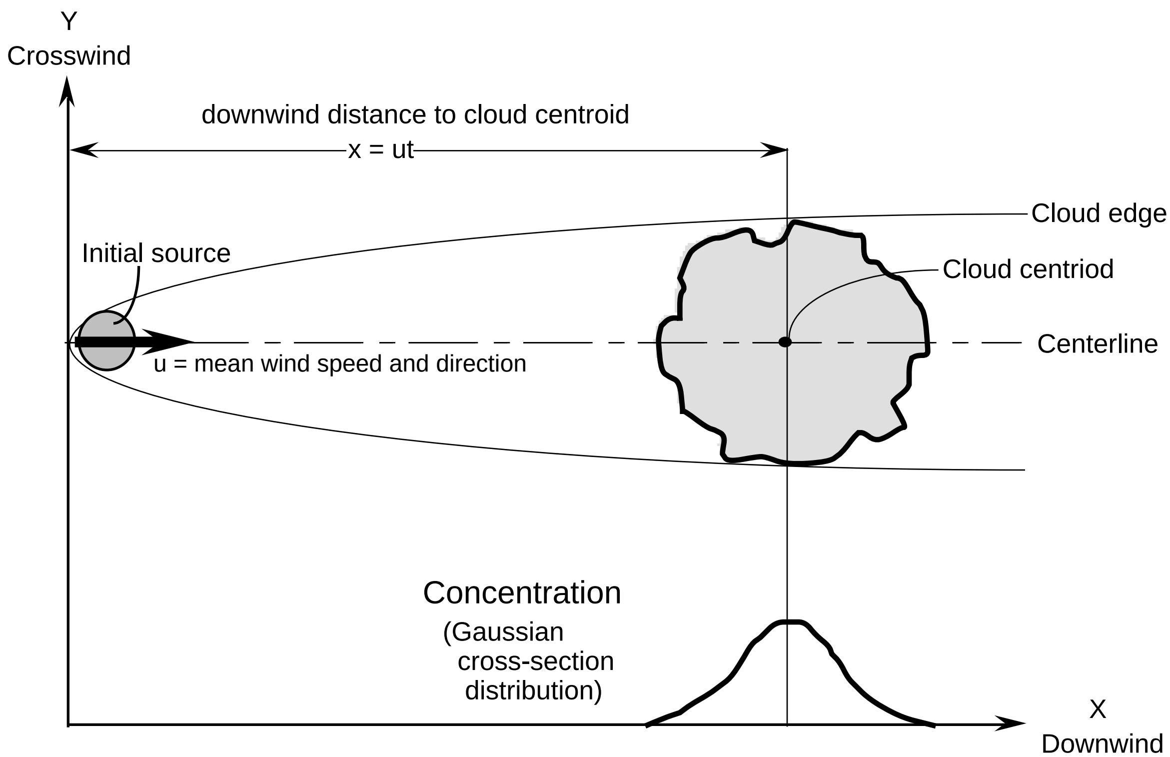

Figure 2. Top view of the REEDM Gaussian plume modeling structure

ARAC MODEL STRUCTURE

Figure 3 illustrates the ARAC model run stream which begins with the interpolation of meteorological inputs over a 3-D grid composed of 50 x 50 x 30 grid cells (MEDIC code). Terrain is then injected into the bottom of the model domain and a mass-consistent wind field adjustment is made by MATHEW (Mass-Adjusted Three-Dimensional Wind field). The wind vectors that transport the cloud are modified depending on the terrain influence, and vertical velocities are created according to the atmospheric stability. While time-dependent plume-rise calculations are being made, the Atmospheric Dispersion by Particle-in-Cell (ADPIC) code computes the transport and dispersion of each source segment using thousands of marker particles, each of which represents a fraction of the total mass released. Dispersion rates are computed locally depending on wind speed and atmospheric turbulence conditions. The cloud is diffused according to the local 3-D diffusivity and the cloud's concentration gradient. Finally air concentrations of the material are mapped at or near ground level using specified contour values.

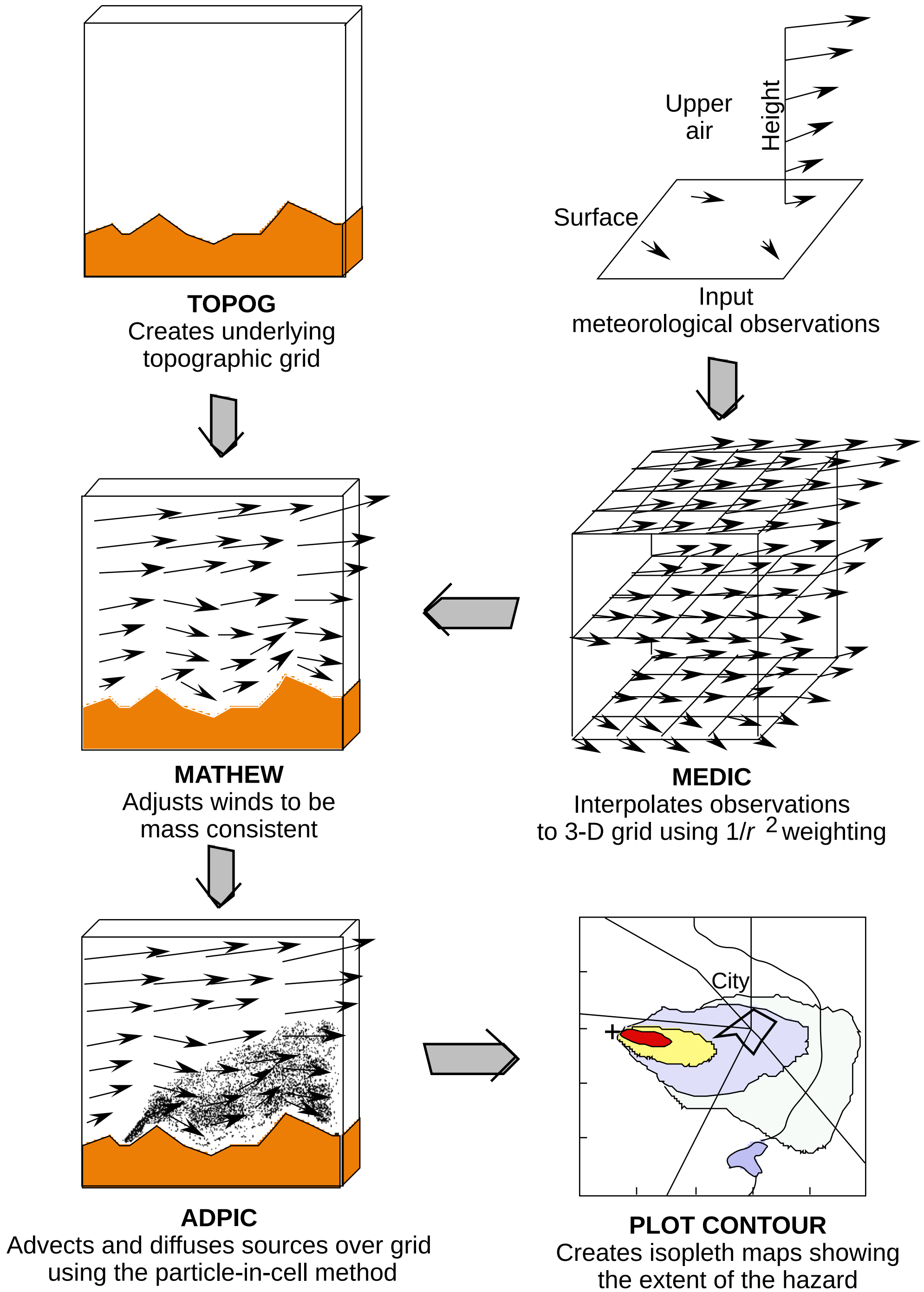

Figure 3. ARAC model run stream

The ARAC numerical modeling system is generalized to treat complex flows in a variety of settings and has been **evaluated against tracer data** for over a dozen releases in many different settings over the last two decades (Sullivan, 1993). In the majority of these studies, computed concentrations were within a factor of 2 of measured values which were averaged over 10-60 minutes. While the model can calculate either instantaneous or averaged air concentrations, we have greater confidence in concentrations averaged over 5 minutes or longer. Maximum concentrations for shorter averaging times (e.g., 1 min to 1 sec) are subject to large variations and are difficult to model with any confidence.

Table 2 summarizes the differences that could be expected between the analytical Gaussian REEDM and the numerical particle-in-cell ARAC models. Operational REEDM calculations include **uncertainty factors** for model inputs (source data and meteorological forecast conditions) as well as uncertainty within the model itself. The ARAC model does not use uncertainty factors, but should reduce the uncertainty in the dispersion calculation. The net result from including wind shear, terrain and ground deposition is that the ARAC codes will produce lower ground-level air concentrations, except where an elevated cloud impacts elevated terrain.

TABLE 2. Differences between REEDM and ARAC models
for several key uncertainty factors

FACTOR	REEDM	ARAC	DIFFERENCE
1. Source rate	TRW test data	Same	None
2. Cloud size and rise	Initialized with calibrated stabilized cloud rise model	Uses time-dependent cloud rise with final height matching REEDM	ARAC model provides detail of dispersion near source
3. Dispersion coefficients	Gaussian model values yet to be validated	Numerical model validated with 12 major tracer studies	ARAC has known total error (factor of 2 for >50% of time)
4. Downwind 3-D wind shear and terrain effects	Not included after cloud rise	Included	ARAC model should produce lower air concentrations
5. Reflection at inversion and ground	Perfect reflection at both inversion and ground	Variable reflection at inversion; deposition at ground	ARAC model will produce lower air concentrations
6. Error in forecasted sounding	A single forecasted sounding is input	Same (However, ARAC could use multiple inputs)	Directional errors in a single forecast sounding would be the same

COMPARISON OF MODEL RUNS

Table 3 compares ARAC and REEDM model results for the **catastrophic abort case** from 2 preparation studies and 3 launches. We compared the ground-level cloud centerline values either at downwind distances of the maximum air concentration or at the population area of concern during the launch.

The initial comparison of the cancelled PK launch on 18 November 1994 showed that the ARAC concentration (converted to a 1-minute average) produced a 7 ppm, which was about 1/3 of REEDM, but still greater than the 5 ppm Tier 2 limit at the time.

Subsequently, ARAC and REEDM were run using several qhistorical soundings representing climatological cases for the January launch window. Each of these runs compared 5-minute averages, before the maxima were converted to 1-second peak concentrations by each model for the Go/No-Go decision. The historical comparisons show that, when population centers ("pop centers") were involved, the ARAC model indicated a "Go" for launch 12 of the 13 cases while REEDM produced only 2 "Go's".

Table 3. Comparison of launch decisions using REEDM and ARAC models for North Base catastrophic abort cases

DATE OF RUNS	MODELED LAUNCH	COMPARED LOCATION	DECISION WITH REEDM	DECISION WITH ARAC
26-29 Dec 1994	Analysis of aborted PK-17A on 18 Nov 94	Base Housing Casmalia	No Go No Go	No Go Go
12-15 Jan 1995	PK case studies for the January window from historical soundings	To the north Base Housing To the south	6 No Go 2 No Go/ 2 Go 3 No Go	6 Go 4 Go 1 No Go/ 2 Go
16-18 Jan 1995	PK-17A launch	Offshore	Go (no pop center)	Go
1 Feb 1995	MM III launch	Southward (offshore)	Go (no pop center)	Go
15-17 Mar 1995	MM III launch	Southward (alongshore) Rotated to Base Housing	Go (no pop center) No Go	Go No Go

Fortunately during the 3 launches in January, February, and March, the winds directed the clouds away from any population centers. However, both models would have produced concentrations above the 10 ppm 1-second limit if the wind direction was rotated over Base Housing for the 17 March MM III launch. It is likely that both models will show that any nighttime launch from the North Base area will exceed the Tier 2 criteria anytime the wind blows towards Base Housing with little directional shear in the vertical.

Table 4 summarizes the general **quantative differences between the models** based on the comparison runs to date at the nearest population center (5-10 km) in each downwind sector. When no significant terrain or wind shears are involved, the REEDM and ARAC models produce about the same concentrations (within a factor of 2). When terrain blocks the cloud to the north or east, the ARAC model shows about a factor of 4 to 5 less concentration at the population centers downwind of the blocking. When significant changes in wind direction with height occur, the ARAC model calculates up to a factor of 4 less than REEDM. However, because each individual ratio depends strongly on the unique combination of meteorological and topographic conditions, that ratio cannot be generalized for a specific location.

Table 4. Ratios of REEDM to ARAC model maxima at population centers

MODELED CONDITION	DIRECTION (and Population Center)	TYPICAL RATIO OF REEDM to ARAC
Flat or rolling terrain and steady winds	Offshore, southward or towards base housing	1-2
Terrain-blocked locations	To the east or northeast (Casmalia, Guadalupe) To the north (6 Trailers)	4-5
Wind shear	Any direction	up to 4

CONCLUSIONS

The catastrophic abort case, when compared to the current Tier 2 (10 ppm HCl) concentration interim guideline, is the limiting case for North Base missile launches at Vandenberg AFB. About 2 dozen model runs were made to compare the maximum centerline concentrations of the ARAC numerical model to REEDM Gaussian model for nighttime launches. When wind shear or terrain effects are involved, the ARAC 3-D calculation can produce up to 5 times smaller concentrations than REEDM at the nearest downwind population center 5-10 km downwind of the launch. The ARAC model would indicate "Go" to launch for the majority of these cases when the REEDM would not. However, for strong, steady winds toward Base Housing, it is likely that both models would concur that the current interim exposure limit would be exceeded.

REFERENCE

Sullivan, T. S, J. S. Ellis, C. S. Foster, K. T. Foster, R. L. Baskett, J. S. Nasstrom, W. W.Schalk. 1993: Atmospheric Release Advisory Capability: Real-time modeling of airborne hazardous materials, *Bull. Amer. Meteor. Soc.* **74:** 2343-2361.

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